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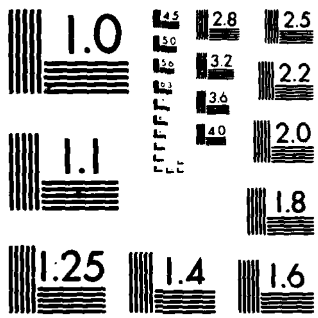

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FOREIGN TECHNOLOGY DIVISION

VERTICAL TEMPERATURE STRATIFICATION OF THE ATMOSPHERE IN AN AREA OF THE HIGH TATRA MOUNTAINS

by

J. Otruba

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VERTICAL TEMPERATURE STRATIFICATION OF THE ATMOSPHERE IN AN AREA OF THE HIGH TATRA MOUNTAINS

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Summary

In this contribution some results are described of aerological measurements made at 1 a.m. at the aerological station Poprad, situated at 709 m above sea level on the southern slope of the High Tatras, the highest peaks of which reach a height of about 2500 to 2650 m. On the basis of aerological measurements made during 1959-1963 the vertical thermal stratification was analyzed up to an elevation of 3000 m above sea level.

According to the average vertical gradient, four basic layers were taken into consideration:

A - temperature inversion, $\gamma \leq -0.2^{o}C/100$ m;
B - isothermal or quasi-isothermal stratification, $-0.1 \leq \gamma \leq 0.1$;
C - thermal stratification with a small vertical gradient, $0.2 \leq \gamma \leq 0.4$;
D - thermal stratification with a vertical gradient, $\geq$ [illegible]/100 m.

These layers were subdivided according to their lower level,

a) $h = 709$ m: A_1, B_1, C_1, D_1: b) $709 \text{ m} < h \leq 2000$ m: A_2, B_2, C_2, D_2;
c) $2000 \text{ m} < h < 3000$ m: A_3, B_3, C_3, D_3.

In this contribution the occurrence of the different thermal stratification and its thickness in the course of the year is recorded. Some characteristics of the ground layer of the atmosphere as well as of the conditions of motion and humidity of the air within this layer are worked out in detail.

Results of aerological measurements obtained from the station Poprad situated at 709 m above sea level in the Poprad Basin on the southern side of

the High Tatra Mountains allow us to analyze some characteristics of the free atmosphere within the area of these mountains, the highest peaks of which reach altitudes from 2500 to 2650 m above sea level. On the basis of nocturnal measurements made at 1 a.m. during the years 1959-1963 the vertical temperature stratification could be followed up to an altitude of 3000 m above sea level. Four different strata could be distinguished according to the size of the mean vertical temperature gradients. These strata could then be subdivided according to their lowest level (Table 2).

Within the atmospheric strata observed with a total thickness of 2291 m (from 709 m to 3000 m above sea level) a temperature stratification, consisting of 3 or 4 layers (Table 1), occurs during the summer half as well as during the winter half of the year. Cases of several temperature strata are then more frequent during the winter half of the year than during the summer half. During the 5-year period observed four occasions with nine temperature layers were identified (during winter).

There is frequently a temperature inversion above the ground surface. Such occur in more than half the cases during an average year. During the course of the year the frequency of the temperature inversions in highest (60-70%) during the months of August to October inclusively and least (40-50%) during winter from November to March (Fig. 1). The annual course of the frequency of ground layer inversions deviates also considerably from the annual course of the radiation balance. As can be seen from Figure 1, the layers D_1 and C_1 are least frequent above the ground surface at midnight in the Poprad Basin. At an elevation above the surface layer the D temperature strata are most frequent, while temperature inversions are very rare (Fig. 2). Less than 10% of the cases of temperature inversions within the annual mean occur at high elevation.

Thereby the frequency of altitudinal inversions follows an essentially different annual course than the frequency of ground layer inversions. The frequency of the altitudinal A strata (A_2+A_3) follows a course opposite to that of the D layers (D_2 + D_3) which agrees well with the annual course of the radiation balance in the lower atmospheric layer. The annual course of the B and the C strata above ground as well as at high altitude is less distinct.

TABLE 1. TEMPERATURE STRATIFICATION WITH DIFFERENT NUMBER OF STRATA.

(1) ZAHL DER SCHICHTEN	(2) HÄUFIGKEIT (%)		
	WINTER-HALBJAHR (3)	SOMMER-HALBJAHR (4)	JAHR (5)
1	2,0	2,4	2,2
2	14,1	17,5	15,8
3	34,2	38,9	36,4
4	27,6	25,1	26,9
5	13,8	11,2	12,5
6	5,6	2,9	4,2
7	2,0	0,8	1,4
8	0,3	0,4	0,4
9	0,4	—	0,2
≥ 4	49,7	41,4	45.6

Key: (1) number of strata; (2) frequency in %; (3) winter half of the year; (4) summer half of the year; (5) year.

TABLE 2. TERMINOLOGY OF THE TEMPERATURE STRATA.

γ in °C/100m	(1) UNTERE GRENZE (h in m NN)		
	h = 709m (am Boden) (2)	709m < h ≤ 2000m	2000m < h < 3000m
$\gamma \leq -0{,}2$	A_1	A_2	A_3
$-0{,}1 \leq \gamma \leq 0{,}1$	B_1	B_2	B_3
$0{,}2 \leq \gamma \leq 0{,}4$	C_1	C_2	C_3
$\gamma \geq 0{,}5$	D_1	D_2	D_3

Key: (1) lower limit (h in meters above sea level); (2) (at ground level).

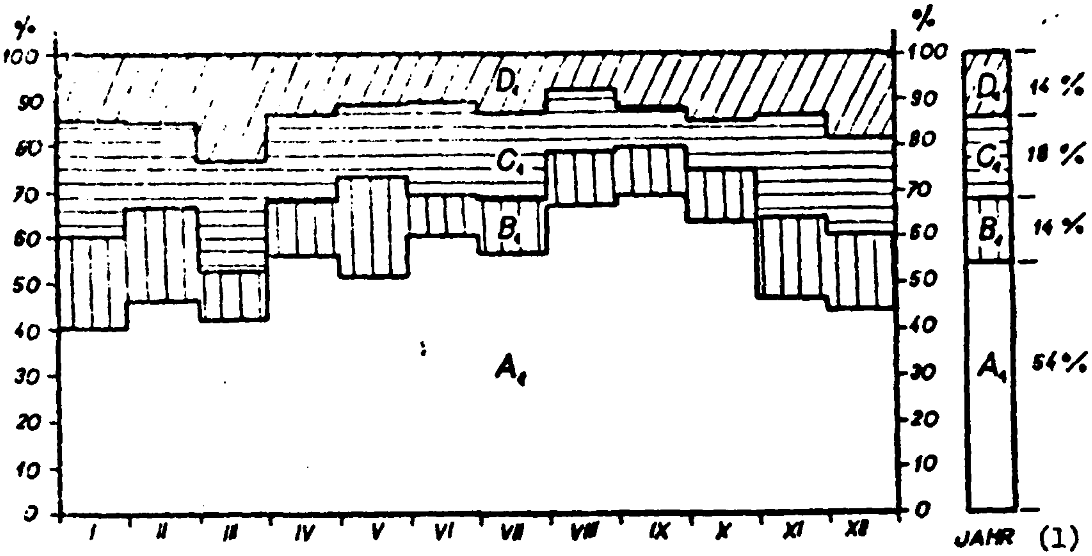

Fig. 1. Frequency of the temperature strata at the ground level.
Key: (1) year.

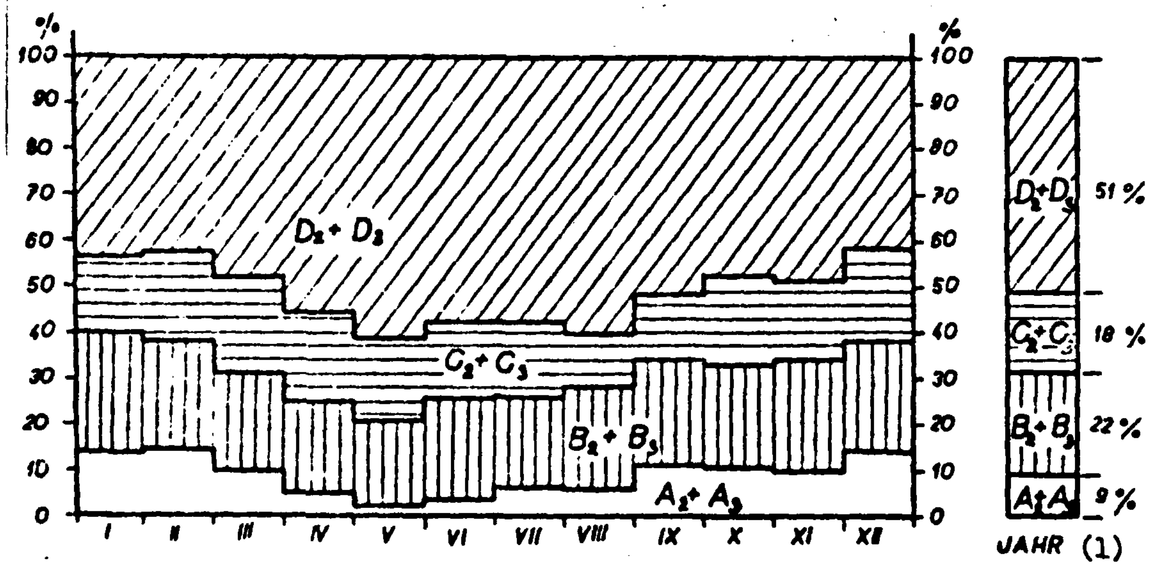

Fig. 2. Frequency of different temperature strata at high elevation (up to 3000 meters above sea level).
Key: (1) year.

TABLE 3. FREQUENCY OF THE STRATA ABOVE THE GROUND LEVEL LAYER.

[illegible] (1)		(2) Häufigkeit (%) Winterhalbjahr (3)	Sommerhalbjahr (4)	Jahr (5)
A_1	A	13.3	4.6	8.4
A_1	B	44.3	51.5	48.3
A_1	C	13.8	7.7	10.4
A_1	D	28.6	36.2	32.9
B_1	A	8.3	0.9	5.0
B_1	B	4.2	3.4	3.8
B_1	C	16.0	9.4	13.0
B_1	D	71.5	86.3	78.2
C_1	A	10.3	1.4	6.4
C_1	B	14.1	5.5	10.3
C_1	C	8.1	4.8	6.7
C_1	D	64.8	84.9	73.6
C_1		2.7	3.4	3.0
D_1	A	26.6	9.7	19.8
D_1	B	30.7	15.5	24.5
D_1	C	11.3	21.4	15.4
D_1	D	22.7	36.9	28.5
D_1		8.7	16.5	11.8

Key: (1) layer above the ground level layer; (2) frequency (%); (3) winter half of the year; (4) summer half of the year; (5) year.

Table 3 illustrates how often the different strata are in position above the ground level layer. There is most often isothermy above the ground level inversion. Above the ground level isothermy and above the C_1 layer there is a D layer and above the D_1 layer another D layer or a B layer. The difference between the six months of winter and those of summer agrees well with the annual and the diurnal heat balance in the lower strata of the atmosphere at a site, typical of a basin.

The dependency of temperature stratification on the radiation and heat balance in the lower strata of the atmosphere is more obvious in the thickness than in the frequency of the temperature layers close to the ground level. This fact is especially valid for the A_1 and D_1 layers (Figure 3). The maximum mean thickness is typical of the D_1 layer and the minimum of the A_1 layer. The maximum mean thickness of the ground level inversion amounts to between 100 and 300 m (in ca. 68% of all the cases). During the six months of winter (October - March) about 1/3 of all days and during summer (April - September) 1/7 of all days have a surface inversion $\geq$300 m thick. The most

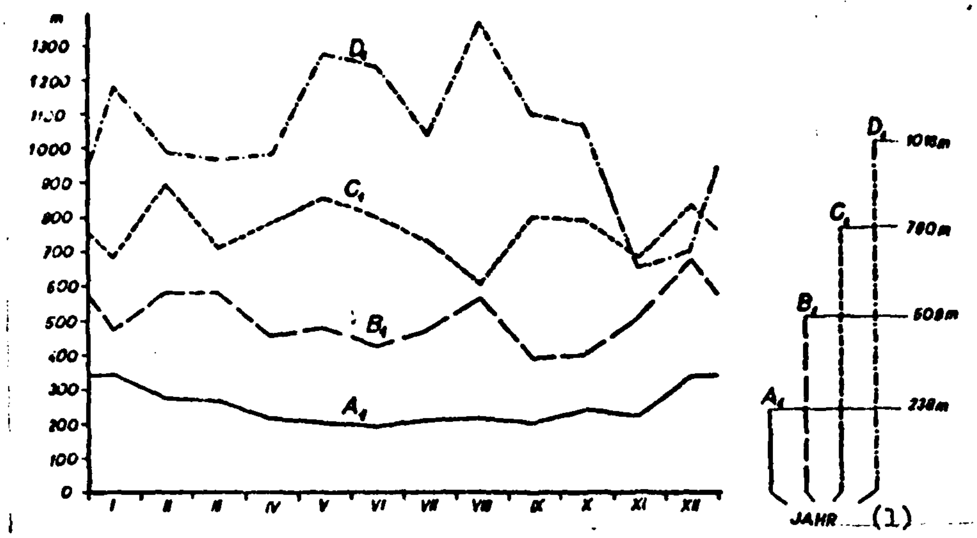

Fig. 3. Mean thickness of the temperature strata close to the ground level.
Key: (1) year.

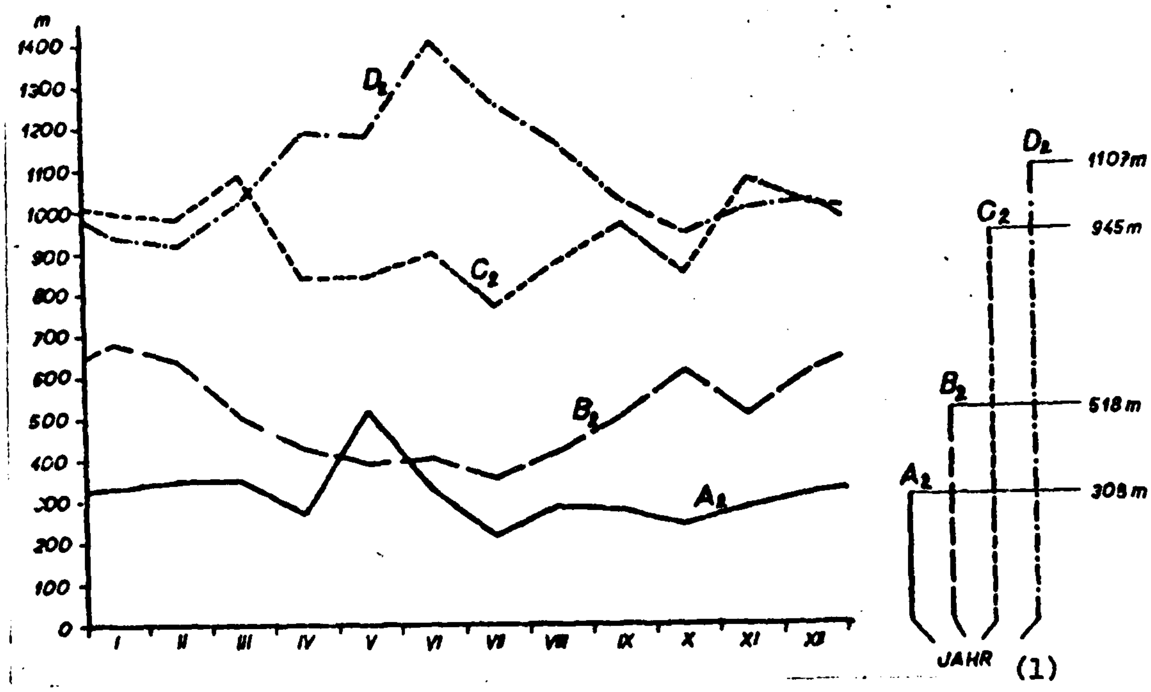

Fig. 4. Mean thickness of high altitude temperature strata (lower level $\geq$ 709 m $\leq$ 2000 m).
Key: (1) year.

frequent thickness of the B_1 layer is from 200 to 600 m (ca. 60%), of the C_1 layer from 300 to 700 m (ca. 48%) and of the D_1 layer from 300 to 800 m (ca. 45%). As illustrated in Figure 4 the mean thickness of the high altitudinal temperature strata (lower level $709 < h \leq 2000$ m) is larger than that of the corresponding ground layer. In order to evaluate the total fraction of the four temperature stratifications (A, B, C, and D) in the atmospheric layer up to an altitude of 3000 m above sea level without taking into consideration at what altitude these strata occur, the mean total thickness of the A, B, C, and D layers is displayed in Figure 5. Except for the four winter months of November to February, inclusively, the D temperature layer comprises in general more than half of the total air layer up to 3000 m above sea level. It is interesting that the secondary minimum of the mean thickness of the inversion layers occurs during November corresponding to the increase in wind speed in the lower atmospheric layer during that month.

The mean thickness of the temperature layer closest to the ground level was also observed. Any combination of the A, B, C strata with their lower limit at the ground level ($h = 709$ m above sea level) was considered as a stable ground layer. The mean thickness of these strata during the individual months is illustrated in Figure 6. It is evident from this figure that the mean thickness of the stable temperature layers at the ground level agrees very well with the corresponding annual course of the radiation and heat balance within the lower atmosphere. A similar annual course can be seen most clearly in a stable layer, starting at the ground level. In spite of the considerable width of the Poprad Basin a stable temperature stratum occurs there at midnight and close to the ground even during the warmest month and measures a few hundred meters thick. Of all the stable strata illustrated in Figure 6 ca. 63% occur on days when they measure ≥ 500 m thick during the six months of winter, while ca. 19% are observed during the summer months. Of days when the thickness is ≥ 1000 m ca. 41% occur during the winter half of the year and ca. 13% during the summer half. Days when the layer is ≥ 2000 m thick amount to ca. 16% during winter and ca. 4% during summer.

The vertical stability increases from midnight toward morning. In order to evaluate the dependency of the temperature stratification on time and on the thickness observed the mean vertical gradients of the A_1, B_1, C_1 and D_1 ground level strata were compared based on the aerological ascent at Poprad

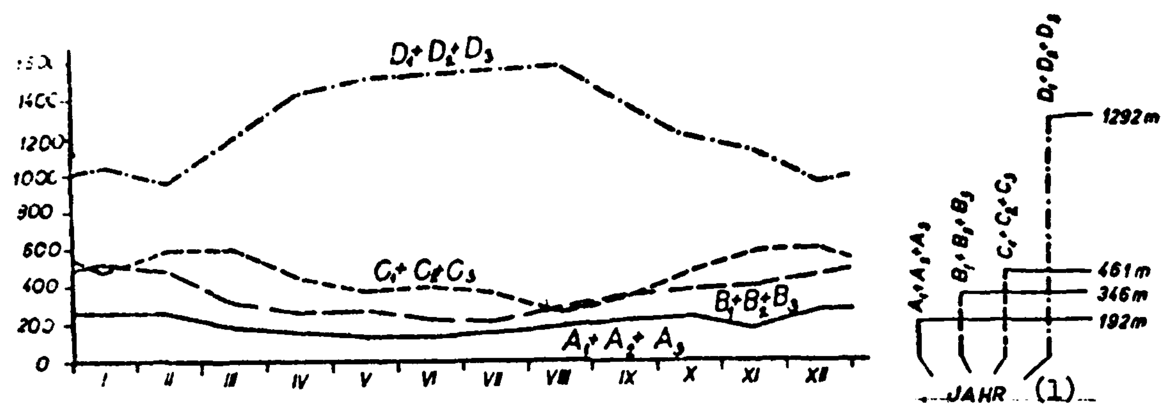

Fig. 5. Mean total thickness of the different temperature strata up to 3000 meters above sea level.

Key: (1) year.

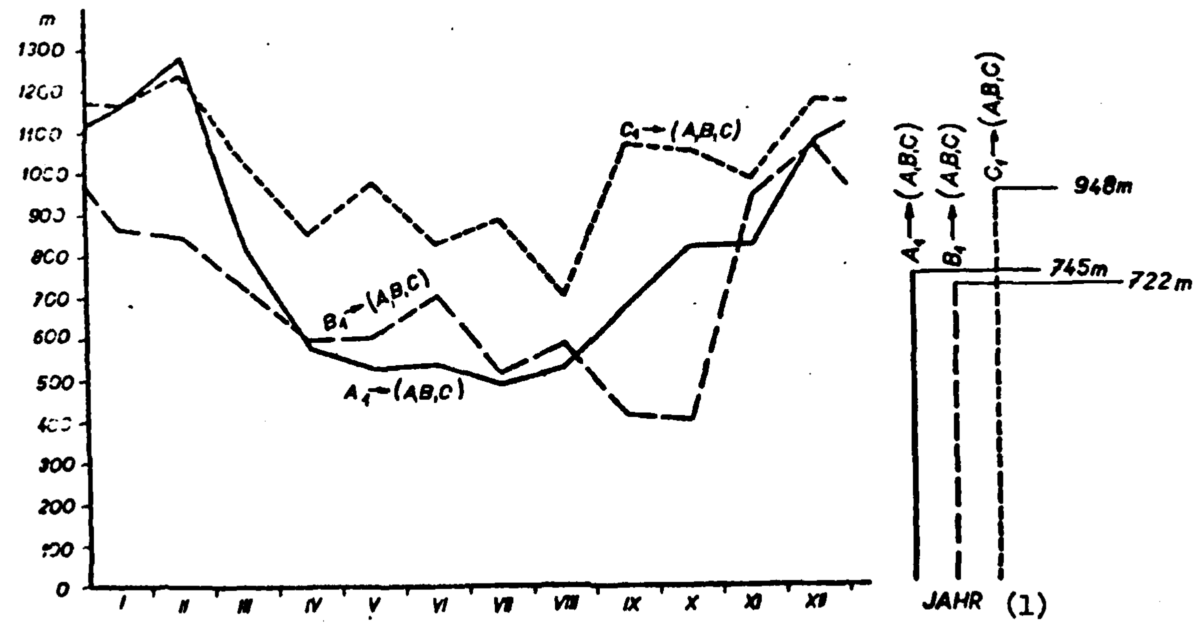

Fig. 6. Mean thickness of the stable ground layers.

Key: (1) year.

with the mean vertical temperature gradients between Poprad and Štrbské Pleso (altitudinal difference 621 m) and between Poprad and Skalnaté Pleso (altitudinal difference 1069 m) according to measurements made at the 2 m level at 7 a.m. The results are displayed in Figure 7. Although it is a question of

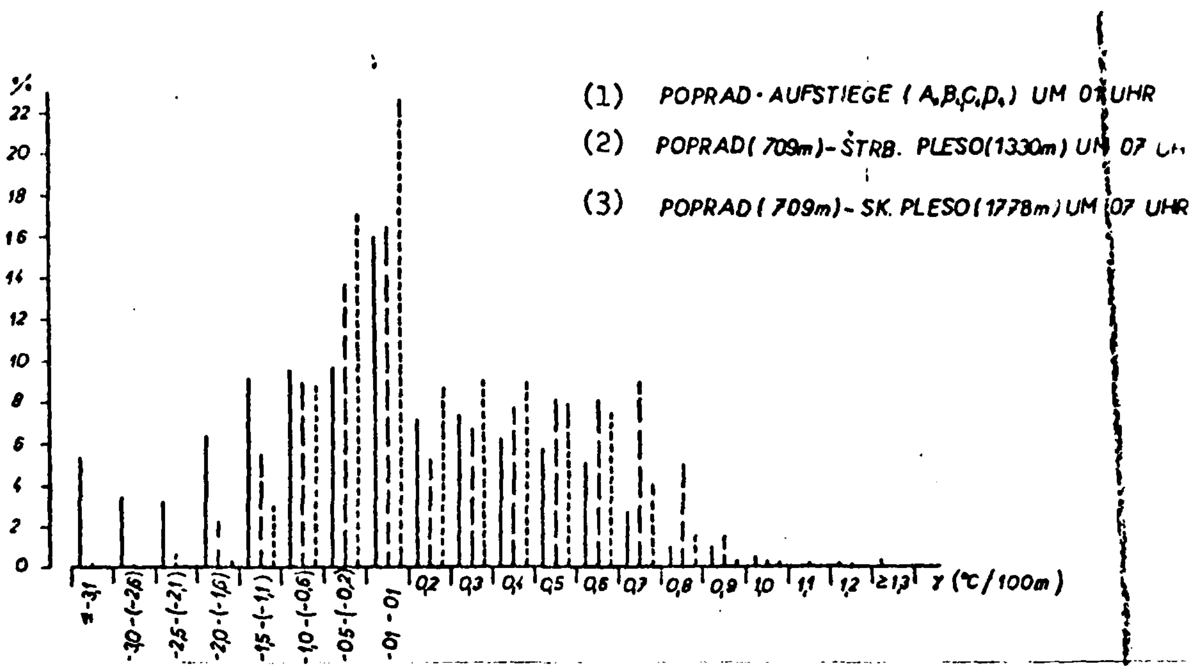

Fig. 7. Frequency distribution of the mean vertical temperature gradients of the surface strata at Poprad (A_1, B_1, C_1 and D_1) during night and between the Poprad, Strbské Pleso and Skalnaté Pleso at 7 a.m. during the winter half of the year.
Key: (1) Poprad ascent (A_1, B_1, C_1, D_1) at 1 a.m.; (2) Poprad (709 m) - Strb. Pleso (1330 m) at 7 a.m.; (3) Poprad (709 m) - Sk. Pleso (1778 m) at 7 a.m.

different thicknesses of the strata observed, the frequency of the corresponding gradients indicates some typical peculiarities of temperature stratification in the lower atmosphere of an alpine area.

The correlation between temperature stratification and wind speed in the ground layer is important from both a meteorological and a practical point of view. Although the Poprad station is situated in a typical basin, the occurrence of calm weather in the layer close to the ground is a rare event even during a temperature inversion. During the 5-year period studied there were a total of 11 cases (1.1%) of inversion ground layers, 50-400 m thick, in which the wind speed amounted to ≤ 0.5 m/sec, while in the other ground layers (B, C, D) no mean wind speed ≤ 0.5 m/sec was observed at 1 a.m. (Figure 8). A mean wind velocity of < 4.0 m/s is typical of the annual mean in respect to 72% of the A_1 strata, 46% of the B_1 strata and 41% of the C_1 strata as well as 36% of the D_1 layers. According to anemographic measurements at 10 m elevation, 20-25% of the cases have wind speeds ≤ 0.5 m/sec.

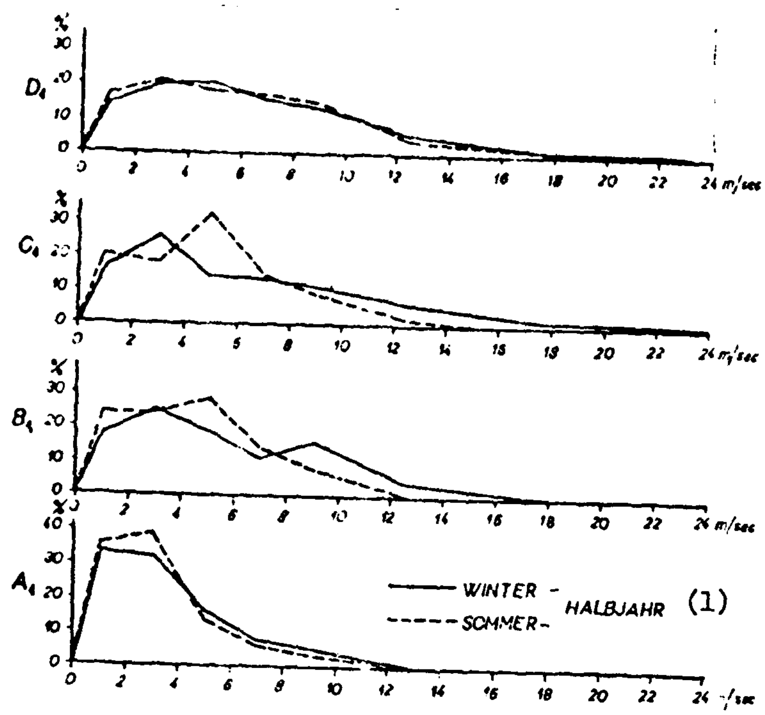

Fig. 8. Frequency distribution of mean wind speed within the temperature strata close to the ground level.
Key: (1) winter-summer half of the year.

This confirms the fact that it is impossible to make an adequate evaluation of the conditions of currents within the entire thickness of the lower layer of the atmosphere when there is a temperature inversion in a basin situation. On the basis of previous measurements of the winds in the surface layer and at high altitude above Poprad it can also be concluded that the majority of the temperature inversions in the lower layer of the atmosphere above Poprad are formed due to local movements of air (at 0.5 to 4.0 m/s) between the steep walls of the adjacent mountains, especially the High Tatras, and the basin. These local winds affect the formation of temperature inversions as well as their intensity and thickness.

There are also certain characteristics regarding the dynamic conditions within the surface layer of the atmosphere, represented by deviations in the wind direction at the lower limit of the temperature layer close to the ground. During the winter half of the year the wind within the inversion layer turns more often toward the left than toward the right with rising elevation. During

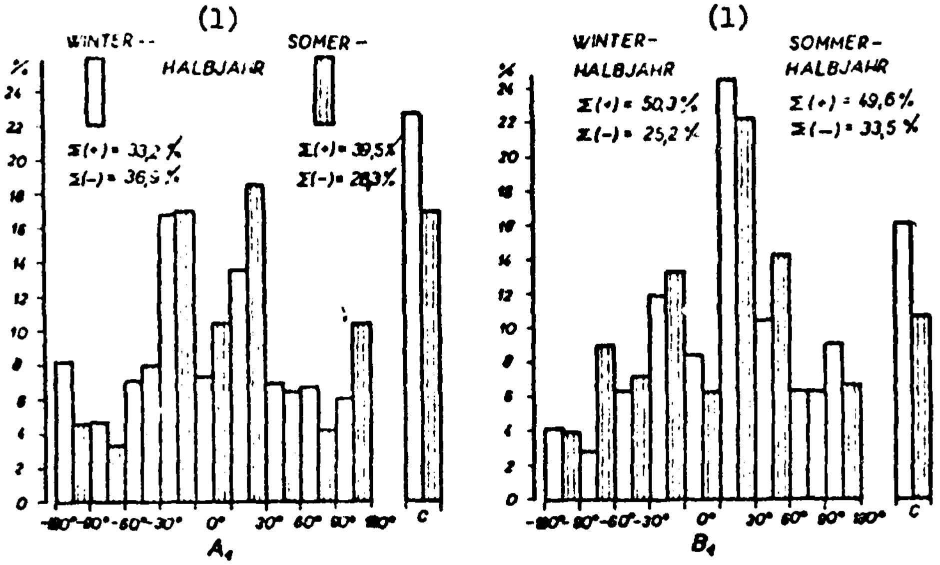

Fig. 9.

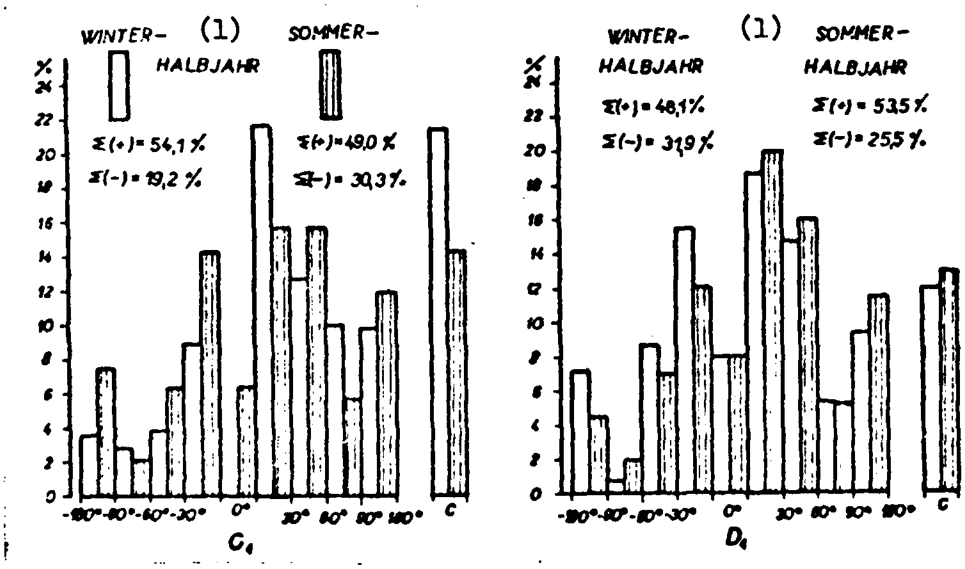

Fig. 10.

Figs. 9 and 10. Frequency distribution of deviations in wind direction at the upper limit of the temperature layers close to the ground.

Example: wind direction at the lower limit 10° / wind direction at the upper limit 120° > deviation + 110°

Key: (1) winter / summer half of the year.

the summer half of the year the relationship is the reverse within this layer. In other surface layers cases of the wind turning toward the right are more frequent than deviations toward the left both during the winter half and the summer half of the year. The difference between deviations toward the left or toward the right within the B_1 and the C_1 layers is larger during winter than during summer, but in the D_1 layer these differences are larger during the summer half than during the winter half of the year. At wind directions from 160° to 290° positive deviations in the ground layer are more frequent than negative ones. At wind directions from 300° to 110°, on the other hand, the negative deviations predominate. These differences have only a minor effect on the total frequency of the deviations since at the Poprad station wind directions from 250° to 290° are extremely predominant and those between 300° and 110° occur only very rarely (Figures 9 and 10).

The average relative humidity within the different temperature strata, especially within the upper ones, has a less distinct or even an irregular annual course. The following monthly data on the relative humidity in the individual temperature strata were observed within the 5-year period studied: *

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